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OPTICAL LOGIC AND SIGNAL PROCESSING USING A SEMICONDUCTOR LASER DIODE-BASED OPTICAL BISTABILITY DEVICE

by

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OPTICAL LOGIC AND SIGNAL PROCESSING USING A SEMICONDUCTOR LASER DIODE-BASED OPTICAL BISTABILITY DEVICE

Zhang Yuancheng, Song Qian, and He Shaowei, of Wuhan University, Wuhan

Abstract: Using an optical fibre-coupled semiconductor laser diode OBD with output feedback pumping, operation in 5 modes(differential gain, bistability, zero-bias ,inverted differential gain,and inverted bistability)has been realized respectively, and 5 elementary optical logic functions(AND, OR, NOT, NAND, and NOR) and some optical signal processing such as limiting, reshaping, and triggering have been implemented.

Key words: optical bistability, optical logic, optical signal processing

I. Foreword

Because of gigantic potential applications, optical bistability devices (OBD) have been widely valued. These devices can be used to accomplish optical signal amplification, pulse compression, amplitude limit, reshaping, logic circuits, and computation, as well as almost all optical signal processing functions [1-3]. As compared with electric signals, light wave frequencies are high therefore there are increases by several orders of magnitude in information capacity and processing speed. No wonder it is held that these devices are the most promising and hopeful elements of future optical digital supercomputers [4].

The authors utilized the output feedback pumping approach [5] to construct an optical bistability system with optical fiber coupling semiconductor laser devices. Under different levels of

feedback and changes in signal coupling polarity, differential gain, anti-differential gain, bistability, anti-bistability, and zero bias, among multiple system operational modes, were realized. Thus, five basic optical logic functions (AND, OR, NOT, NAND, and NOR) are accomplished, in addition to such optical signal processing functions as signal amplitude limiting, reshaping, and pulse triggering. In this article, these experimental results are reported and briefly analyzed.

II. Experimental Setup

Fig. 1. shows the experimental setup. Within the dotted lines in the figure, there is a semiconductor laser bistability system with optical fiber coupling output of feedback pumping. In the system, under excitation of constant bias current I_b of the excitation source S, the optical fiber coupled type SSD-1S1 GaAlAs double-heterojunction semiconductor laser device (LD) emits infrared light with wavelength of 0.87micrometer and power P, which is coupled with a tail fiber to be sent into a Y-type optical fiber coupler (shunt) Y. One pass of light with optical power f_p (feedback coefficient f<1) travels through a type GT101 Si-PIN optoelectronic diode for reception. Then, on passing through current amplifier A, amplify the optical current to form feedback current I_f for feedback to LD in joint excitation with I_b. Another pass of light optical power travels through the other optoelectronic diode D' of the same type for reception, thus an electric signal waveform indicating the OBD output light signal. These signals are fed and observed by a type KIKUSUI COS 5021 double-trace scope. The OBD input light signal P_i is excited by signal source G and coupled with an optical fiber to generate a GaAlAs light-emitting diode (LED). Also coupled with D, the corresponding optical current is amplified by A and is also included in I_f. The waveform of the input optical signal is the same as the waveform of the electric signal generated by G. There are triangular waves, square waves, harmonic waves, as well as their differentials and pulses to generate an integrated circuitry in G.

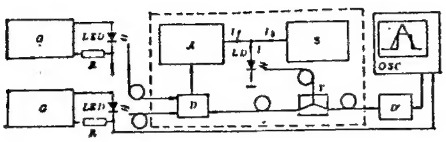

Fig. 1. Experimental setup

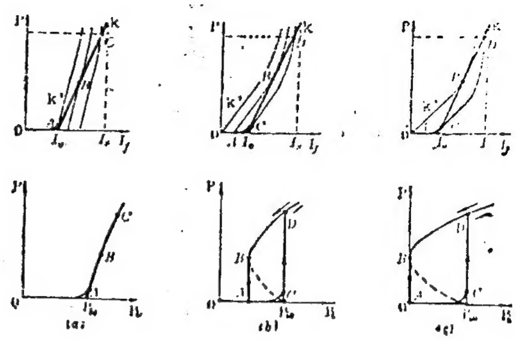

Fig. 2. Operational modes of OBD
(a) Differential gain;
(b) Bistability;
(c) Zero bias;

The various above-mentioned optical fiber coupled power variables are coupled into D, each with a precise optical fiber microadjuster. Therefore, the feedback coefficient f can have changed shunt ratios through selected Y and also with microadjustment of the corresponding precise microadjuster in order to achieve the magnitude required by experiment.

III. Operational Modes

The operational principle of the system can be briefly explained by using Xiaochuan's [translator: a Japanese name given in Chinese pronunciation] [6] graphic solution method. The solid lines in the upper portion of Fig. 2 indicate the output properties of LD. Assume that the ascending inclination of output power P over the threshold value is K (mW/mA). $I_0 = I - I_b$. I_{th} is the actual threshold value excitation current of LD, and I_b is the bias current.

One of the important factors of OBD operation is feedback saturation or feedback nonlinearity. The saturation regime of this system is due to gain saturation of current amplifier A, not

the saturation of the optoelectronic diode. Detection with an optoelectronic diode is linear, and its output optical current is:

$$i = S(Pi + fP) \tag{1}$$

Here, S is the detection sensitivity (microampere per microwatt) of GT101; however, the current amplifier has saturability.

$$I_f = G_i/[1 + i/I_s] = GS(P_i + fP)/[1 + (P_i + fP)/P_s] \tag{2}$$

In the equation, G is the unsaturated gain of the current amplifier; $I_s=SP_s$ is the saturated (input) current; and P_s is the corresponding saturated optical power. Then, on the same $P-I_f$ plot, the feedback property (2) is a family of curves with P_i as the parameter, as shown by slender solid lines in the figure. These curves have the same initial inclination (related to feedback parameter f):

$$K' = (GSf)^{-1} \tag{3}$$

From Fig. 2, when K<K' or f<f $(GSK)^{-1}$, the system operates in the differential gain mode (Fig. 2a). When K>K', or $f>(GSK)^{-1}$, the system operates in the bistability mode (Fig. 2b). With greater feedback values, in other words, $f \geqslant [GSK(1-2\sqrt{I_0/I_s})]^{-1}$ or $K' \leqslant K(1-2\sqrt{I_0/I_s})$, the lower jump point of the system bistability return moves to the origin (zero output light intensity); at that time, the authors call it the zero-bias operational mode (Fig. 2c). Since the system is active, the optical gain can be very large. Therefore, this third operational mode can be used to switch and control the weak light against the intensive light when the bias light is not required. Therefore, in practice this is quite attractive.

If in the Fig. 1 setup, another optoelectronic diode is used to detect the input light signal P_i and the phase of the optical current obtained is reversed, then blended with the feedback optical current detected by D and fed into A for amplification. Thus, system operations of two modes can be realized: anti-differential gain (K<K'), and anti-bistability. We will see in

the following when these two operational modes are utilized, we can accomplish the NOT, NAND, and NOR functions.

In Fig. 3, oscillograph pictures (a) through (e) show the actual operational properties of all five modes mentioned above.

IV. Fundamental Optical Logic

By using either differential gain or bistability modes, AND and OR can be accomplished. When executing AND gate under the bistability mode, the summation of the pulse amplitude of input A and of input B should be greater than the threshold value of upper jump of the OBD. However, any one of them is smaller than this threshold value. Therefore, only A and B come simultaneously, can the system output optical logic 1; otherwise, the output is logic 0. In the oscillograph pictures, Fig. 3 (g) and (h) are AND gate waveforms. Here, as limited by the double-trace oscillograph, three waveforms of two inputs and one output were photographed at separate times because of double-trace oscillography. The repeated one is used as the phase reference (same in the following). For the OR gate, it is required that either the input value A or B should be greater than the jump threshold value on the OBD. Therefore, any input can make the system jump from 0 to 1. Fig. 3 (i) and (j) are the operational waveforms of the OR gate.

Both the anti-differential gain and the anti-bistability modes can be used in the NAND gate (phase reversal). Fig. 3 (k) is the operational profile of the NAND gate. From the figure, the light input and light output are exactly opposite in phase.

Both the anti-differential gain and the anti-bistability mode can be used in the NAND or the NOR gate. In the anti-bistability mode, the former requires that both inputs are lower than the lower jump threshold of the OBD; however, summation of the two is higher than this value. Therefore, only when two

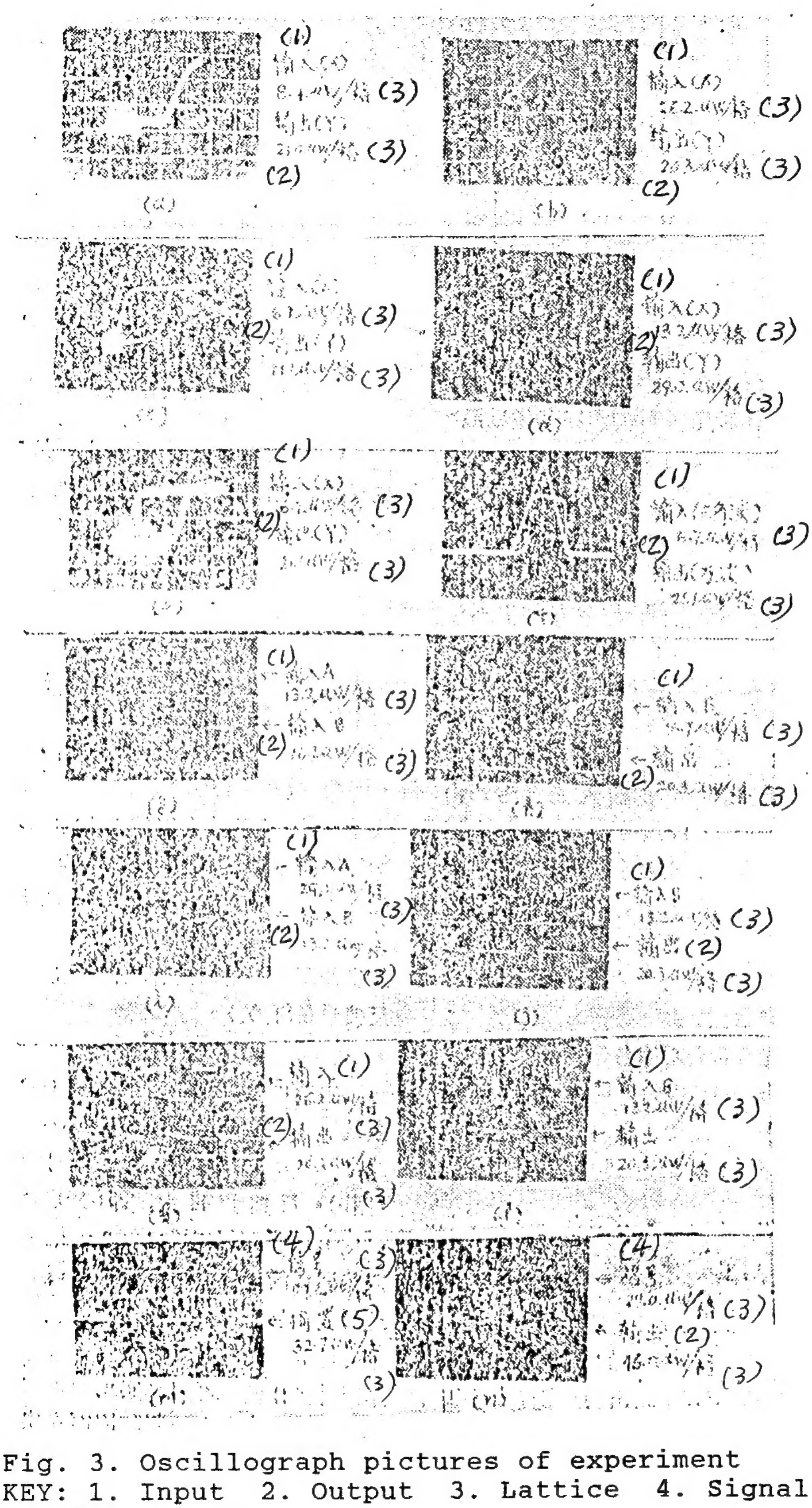

Fig. 3. Oscillograph pictures of experiment
KEY: 1. Input 2. Output 3. Lattice 4. Signal
5. [Illegible]

inputs come simultaneously can the system output change from 1 to 0. In the latter, it is required that both inputs are higher than the lower jump threshold value of the OBD. Therefore, any input can enable the system to change from 1 to 0. Fig. 3 (i)and (l) are the oscillograph pictures of the NOR gate.

V. Optical Signal Processing

Due to saturation of current amplifier A of the feedback branch, the system has good amplitude limiting function for light signals. Since there is intensive positive feedback in the system, the upper and lower jumps of the bistability return are very steep (the time of instantaneous response is determined by the response time of Si-PIN optoelectronic diode and current amplifier), therefore the system has desirable reshaping function for light signals. In other words, for various nonrectangular and anomalous waveforms, the system changes them into square waves with limiting and reshaping. As shown in Fig. 3 (f), under the bistability mode, the input of triangular waves will generate the output of square waves. This clearly indicates the system functions of limiting and reshaping. In this process, there is also light gain.

We know in optical fiber communication relay stations that it is required to amplify and reshape the light pulses that become anomalous due to chromatic dispersion of the optical fiber, into pulse code modulated square waves, thus reducing the code error rate. In addition, the system has already carried out a 200-fold gain in optical signals [7]. Therefore, optical fiber communication is very attractive.

From the return in Fig. 2b, differential and pulse signals with appropriate or fixed pulse bias can change the system from low to high or high to low, and maintain the situation until the arrival of the next signal. This indicates that the system has the functions of information storage, switching, pulse counting, and pulse triggering. Fig. 3 (m) and (n) indicate waveforms of

light impulse triggering.

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